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Forensic dental identification using two-dimensional photographs of a smile and three-dimensional dental models

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TITLE:

Forensic dental identification using two-dimensional photographs of a smile and three-dimensional dental models: a 2D-3D superimposition method.

ABSTRACT:

Photographs of a person smiling may provide valuable information about their anterior dentition. These images can be an alternative ante-mortem (AM) dental source in cases with no dental records, which gives the forensic odontologist a significant opportunity for comparative dental analysis. There are no reported studies that have investigated the reliability of a superimposition technique using 2D photographs of a smile and 3D dental models in dental identification. The aim of this study was to explore novel odontological methods by combining 2D photographs with 3D dental models, simulating a dental identification scenario. The objective was to increase the accuracy of dental identification using an AM photograph with the aid of 3D imaging as an alternative to post-mortem (PM) photographs. The study comprised of 31 3D dental models (simulating PM information) and 35 digital photographs (simulating AM information). The data was analysed in two phases: Phase I- Visual Comparison of 2D-3D images and Phase II- 2D-3D superimposition after a wash out period. Both methods were analysed by the principal investigator. Further, one-third (ten) of the sample was evaluated by six raters (three experienced forensic odontologists and three forensic odontology MSc. students). The inter-rater agreement was assessed using intra-class correlation (ICC 2, 1, absolute). The results of the study suggest that the inter-rater and intra-rater reliability using 3D superimposition was highest (ICC $\approx$ 1.0). In summary, there was an increase in match rates and higher certainty among the opinions reached when using the 2D-3D superimposition method. The procedure attempted to reduce the limitations of previously existing 2D methods and is intended to assist forensic experts with a reliable method in photographic dental identification when expressing conclusions on a case.

Keywords: Forensic odontology; Photographic Dental Identification; Digital Photographs; 3D superimposition; 3D dental models.

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1. Introduction:

Comparative dental identification is the most efficient and cost effective means of scientific human identification methods when compared to fingerprint and DNA analysis [1,2] in scenarios such as advanced decomposition or incineration. Forensic odontology has been designated as one of the three primary identifiers by the INTERPOL by which identification can be confirmed [3]. The methodology is based upon comparison of AM and PM dental data which may include dental charts, intra-oral and extra-oral radiographs, clinical photographs, study casts and dental prostheses. Positive identification using this methodology is often achieved with a high degree of reliability and accuracy but the availability of reliable and accurate AM dental records is fundamental for this analysis [1].

Traditional forensic odontology techniques are usually unsuitable in cases where the AM dental records of the victim are not available or insufficient. Photographs of the person smiling may provide valuable information about their anterior dentition. McKenna [4] explored the role of the anterior dentition by enlarging AM and PM photographs to life size to enable accurate superimposition. The characteristics for identification visible in a photograph of a smile comprise the shape, position, angulation, size, dental anomalies and incisal alignment of the anterior dentition [5].

A few case reports have been published on the use of photographs of a smile in positive dental identification [6-8]. The AM photograph enabled the application of direct comparison of morphological traits, dental superimposition and the analysis of the incisal contours of the anterior teeth [9]. Dental identification using photographic superimposition became important with the increasing number of cases with no dental records [10]. In such circumstances, photographs available from family members, through social networks or friends may provide significant opportunity for analysis.

Advances in digital technology and software have greatly improved the interpretation techniques for imaging photographic data. Studies on dental superimposition techniques [10,11] were proposed using Adobe Photoshop® for enhanced comparative dental analysis of two-dimension (2D) AM and PM photographs. Forensic Odontology relies upon the uniqueness of the human dentition in terms of tooth characteristics, their alignment and orientation within the arch, tooth shape and dental treatment interventions. ~~Coroners frequently rely upon forensic odontologists in order to establish an identity by utilising the uniqueness of the dentition~~ [12]. Some studies have investigated the uniqueness by analysing the upper and lower anterior dentition in the general population [13] and the dentitions of orthodontically treated patients [14,15].

With the advent of 3D technology; 3D optical laser scanners and intraoral scanners, opportunities have arisen for reliable and accurate methodologies for forensic studies [16]. When considering photographic evidence, if the image quality permits comparison, a dental superimposition can be performed between a 3D model of a given dental cast and the 2D image [10]. Studies by Sheets et al. [16] and Blackwell et al. [17] reported the free manipulation of 3D digital dental casts on different axes as an advantage, compared to a 2D image analysis and have also highlighted the realistic 3D perspective. Tuceryan et al. [18] and Martin-de-las-Heras et al. [19]

worked on the possibility of accurately extracting digital 3D dental contours using specific software and algorithms.

There are no reported studies that have investigated the reliability of a superimposition technique using 2D photographs of a smile and 3D dental models in dental identification. The aim of this study was to explore novel odontological methods by combining 2D photographs with 3D models, and to see if 3D imaging in the field of forensic odontology can assist with dental identification as an alternative to PM photographs.

2. Materials and Methods:

This study protocol has been approved by the East of Scotland Research Ethics Service, REC reference: 17/ES/0144.

2.1 Data Acquisition:

Patients who had consented for their records to be used for research purposes from the Orthodontic clinic at Dundee Dental Hospital, Scotland, were considered. The post-orthodontic treated dental casts and their corresponding digital photographs of the patient smiling were acquired by the principal investigator (PI) over a period of six months. The digital photographs of the patient smiling (pre-and post-orthodontic treated) were taken by clinical photographer using a Nikon D610 SLR camera. The inclusion criteria were intact dental casts, photographs with front teeth visible in a smile, (from canine to canine) and frontal view photographs (photographs which were obtained when the subject's face is pointing directly towards the camera lens). All the patient identifying information was removed and a unique study code was assigned to each dental cast and the corresponding photograph by another researcher. The PI conducted the study and was provided with the identifying codes at the end of the study.

2.2 Study Design:

This study was conducted by simulating a dental identification scenario. The data collected consisted of dental casts of 31 patients which were all of post-orthodontic patients. Of the 31 dental casts, only 24 corresponding / matching (68%) digital photographs (uncalibrated) were obtained. Eleven digital photographs of post-orthodontic patients were included as non-matches (32%) which constitutes to a total of 35 digital photographs. Additional levels of complexity with more non-matches were introduced into the design so that the uncertainty of identification of matches would require a greater degree of scrutiny on behalf of the investigator(s).

The smile portion in the photographs were cropped using Adobe Photoshop® CC 2017 (Mountain View, California) and saved in TIFF format. For the purpose of this study, these cropped "photographs of a smile" were considered as "2D cases". The dental casts were laser scanned to create indirect 3D digital images of dental models using R700 3Shape Orthodontic Study Model Scanner (Copenhagen, Denmark) in stereolithography (STL) format. These 3D models were considered as "3D cases". The time interval between the patient's photographs and digitalisation of the casts into 3D models was six months.

The data was analysed in two phases: Phase I - Visual comparison (VC) of 2D-3D images and Phase II - 2D-3D superimposition. Both methods of comparison were analysed by the PI. One-third of the sample (ten cases - 33%) was assessed by six raters (three forensic odontologists (FOs) and three MSc. students in Forensic Odontology) for inter and intra-rater agreement (see Fig. 1).

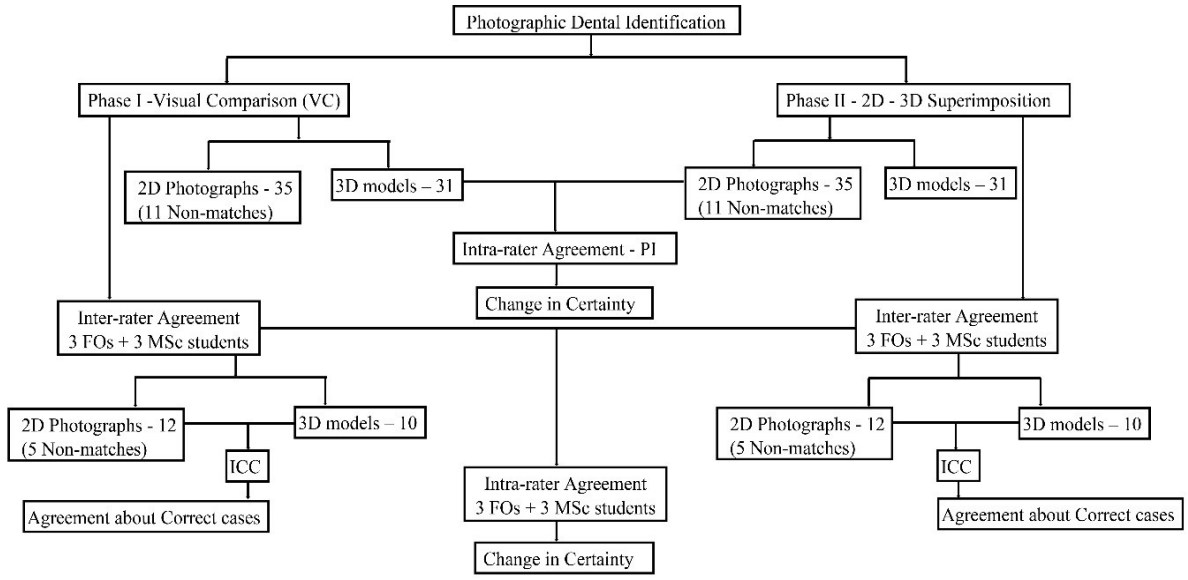


Fig. 1. The study design shows a dental identification scenario with the methods of comparison, analysed by the PI and raters – Forensic Odontologists & MSc. students.

The methods of comparison is described below. Dental features analysed during visual comparison and 2D-3D superimposition were: tooth size, shape, incisal contours and alignment within the arch.

Phase I- Visual Comparison (VC): Thirty-one 3D dental models were visually compared with 35 digital photographs (24 matching and 11 non-matching) showing upper and lower front teeth (canine to canine) by the PI and the results were analysed.

1. The 3D model (STL file) was imported into 3D Rhinoceros 5.0 software (Robert McNeel & Associates, Seattle, USA, 2018) [20] which enabled to orient the dental model in 3D.
2. The folder containing 2D photographs of the person smiling (cropped) was opened separately (with Windows Photo Viewer) and viewed for comparison.
3. Each 3D model was compared with all the available 2D photographs by visual comparison – characteristic dental features visible in the image were analysed.
4. The conclusions/opinions reached were based on the International Criminal Police Organization (INTERPOL) Disaster Victim Identification (DVI) guidelines [3] as follows, Identity Established, Probable, Possible, Excluded and Insufficient evidence.
5. This procedure was repeated for all the 3D models.

Phase II: 2D-3DSuperimposition: After a wash out period of four weeks, the second phase of comparison was conducted by the PI using 3D Rhinoceros 5.0 software. 2D photographs were superimposed upon the 3D digital models, see Fig. 2.

1. Each 2D photograph was imported into the 3D Rhinoceros imaging software for 2D-3D superimposition.
2. As all the photographs are of frontal view and were uncalibrated, a linear measurement of the upper right/left central incisor of the 3D model was recorded, which helped as a guide for enhancing the cropped smile image with visible incisors to approximate with the incisors in the 3D model (Image ‘a’ in Fig. 2).

3. The 3D model was reoriented to correspond to the arch position and teeth alignment in the photograph.
4. The 2D photograph was repositioned to the front of the 3D scan to conduct a superimposition.
5. The image was made transparent to appreciate the features of the 3D model by reducing the opacity with the help of transparency slider setting. Approximately 45-55% setting is usually sufficient and this was considered as 2D overlay (Image 'b' Fig. 2).
6. Once the 2D overlay and 3D model were correctly oriented and anterior teeth outlines from the smile in 2D image superimposed on the teeth visible in the 3D model (indicated by arrows), the outline of the outer margins of every tooth was analysed for degree of correspondence during 2D-3D superimposition (Image 'd' Fig. 2).
7. Thirty-five photographs were superimposed upon each 3D model (31 cases), for a total of 1085 superimpositions.
8. The conclusions/opinions were recorded for all the 3D cases according to the INTERPOL DVI guidelines as above.

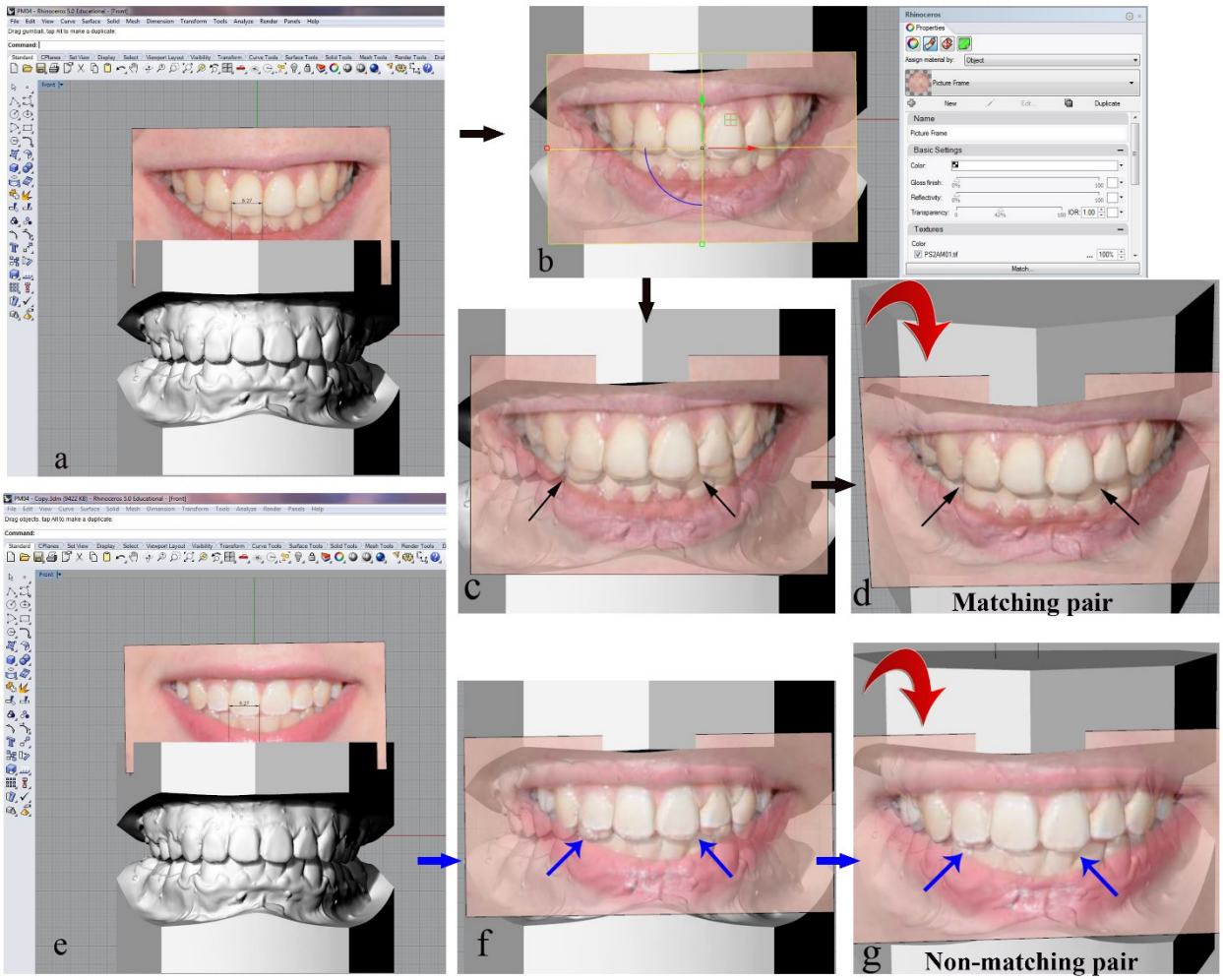


Fig. 2. 2D-3D superimposition using Rhinoceros 3D software: **a.** 2D image size approximation with the incisor in the 3D model (case 1) as a reference landmark; **b.** 2D image superimposed upon the 3D model and converting into overlay; **c,f.** 2D transparent overlay with underlying 3D tooth outlines (indicated by arrows); **d.** Reorientation of the 3D model (indicated by red arrow) according to the teeth alignment in the smile with incisal contours and tooth outlines useful for analysis (indicated by black arrows); **e.** Similar type of dental pattern (case 2) as in image **a**; **g.** Non-alignment of the 2D image tooth contours with the 3D tooth outlines after reorientation (indicated by blue arrows).

The INTERPOL conclusions that were available to the odontologists following comparison of PM and AM dental records include:

a. Identification established (absolute certainty the PM and AM records are from the same person).
b. Identification probable (specific characteristics correspond between PM and AM but either PM or AM data or both are minimal).
c. Identification possible (there is nothing that excludes the identity but either PM or AM data or both are minimal).
d. Identity excluded (PM and AM records are from different persons).
e. Insufficient evidence (neither PM nor AM comparison can be made).

2.3 Inter-rater Agreement:

Ten 3D models (33%) were selected at randomly using online random number generator tool [21] from the 31 3D models. A total of 12 2D photographs (seven matching and five non-matching photographs of post orthodontic patients) and 10 3D models were provided to six raters – three qualified and experienced forensic odontologists and three Master of Science (MSc.) students. The MSc. students were current students in the department of forensic odontology that had completed the dental identification module. All hold a dental qualification. The assessment was performed in two phases; Phase I – Visual comparison and Phase II – 2D-3D superimposition method as described in the methods of comparison and the results were analysed (again: ICC 2, 1 absolute). During Phase II each rater performed 120 superimpositions in total; 12 photographs superimposed on each 3D model (10 cases were used in total). The purpose of this was to find out whether the raters were able to identify the correct match and to test their agreement with each other.

The study hypothesis was that a 2D-3D superimposition method will aid dental identification by comparing photographs of the person smiling and digital dental models with the methodology reliant upon the alignment and morphological traits of teeth for any individual.

Statistical Analysis for the inter-rater agreement was assessed using intra-class correlation (ICC2, 1 absolute) with IBM® SPSS Package Version 22 (New York, USA).

3. Results:

Visual Comparison of 31 3D dental models with 35 2D digital photographs followed by 3D superimposition. The identifying codes for the correct matching 3D-2D pairs were verified with the conclusions reached.

3.1 Phase I – Visual comparison:

In the visual comparison of 2D photographs and 3D dental models (cases), conclusions were reached in all 31 cases by the PI (Table 1). One case was wrongly concluded (false positive), i.e. the correct 2D match was "excluded" and a non-match was considered as a "possible" match.

3.2 Phase II: 2D-3D Superimposition:

Through the application of 3D superimposition method, it enabled the PI to reach conclusions in all 31 cases efficiently and were all correct; i.e 24 cases (77%) with correct matchings (Table 1 – 3D superimposition) and no matches or exclusion for seven cases (23%). There was an increase in the number of "established" cases, while the "possible" cases decreased. With this method, PI was also able to "correctly exclude" all the 2D non-

matches (Fig. 2); in total 11 2D cases (32%) with no corresponding matches (true negatives). A total of 1085 superimpositions were conducted when analysing 35 photographs and 31 3D model.

3.3 Intra-rater Agreement - PI:

A considerable change of certainty among the opinions reached by the PI was observed between the methods of comparison. There was a change of opinion in 21 cases (68%) and no change in in ten cases (32%). The PI was able to identify the "correct match" during 3D superimposition phase which was "excluded*" in visual comparison (Table 2).

Opinion/conclusion reached by the PI	Case(s) by Visual comparison method	Case(s) by 3D Superimposition method
Identity Established	0	9
Probable	18	14
Possible	12	1*
Excluded*	1*	7

Table 1 shows the type of conclusion(s) reached by the PI using Visual comparison & 3D superimposition methods for the 31 '3D cases'. One* correct 2D case was excluded.

Change of Opinion by PI:	Case(s)
Probable to Established	8 (26%)
Possible to Established	1 (3%)
Possible to Probable	4 (13%)
Possible to Excluded	7 (23%)
Excluded* to Possible	1 (3%)

Table 2 Total change of opinions by the PI in 21 cases.

3.4 Inter-rater Agreement:

The forensic odontologists and MSc. students assessed ten 3D models and 12 photographs (seven matches - true positives and five non-matches - true negatives) by both methods of approach, Phase I and II as described above in the methods of comparison. Below is an example of a 3D case and the conclusions reached by six raters for all the 2D cases (photographs) provided for Phase I analysis as shown in Table 3. Codes assigned to the conclusions were; Established-4, Probable-3, Possible-2 and Excluded-1.

3D Case	Correct Case	2D Cases	Forensic Odontologists			MSc. students		
			Rater 1	Rater 2	Rater 3	Rater 1	Rater 2	Rater 3
3D case 1	-	2D Case 1	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
3D case 1	-	2D Case 2	Possible	Excluded	Possible	Possible	Excluded	Possible
3D case 1	-	2D Case 3	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
3D case 1	-	2D Case 4	Excluded	Excluded	Possible	Excluded	Excluded	Excluded
3D case 1	**Yes**	**2D Case 5**	**Possible**	**Possible**	**Probable**	**Probable**	**Possible**	**Possible**
3D case 1	-	2D Case 6	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
3D case 1	-	2D Case 7	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
3D case 1	-	2D Case 8	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
3D case 1	-	2D Case 9	Possible	Possible	Possible	Excluded	Excluded	Possible
3D case 1	-	2D Case 10	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded
3D case 1	-	2D Case 11	Possible	Possible	Possible	Possible	Possible	Possible
3D case 1	-	2D Case 12	Excluded	Excluded	Excluded	Excluded	Excluded	Excluded

Various levels of agreement among the raters is seen in Table 3, presenting not only the ratings of the correct case but how they rated all the incorrect cases/non-matches. In the above case example, all six raters did not

Table 3 An example of a 3D case and the conclusions reached by six raters - Forensic Odontologists and MSc. students.

exclude the correct case, however, opinions differed for the other cases. Of the ten 3D cases provided, only seven 3D cases had correct 2D matches while three cases did not.

3.4.1 Phase I – Visual comparison:

A spread of opinions were reached for the 3D cases provided. The seven "correct 3D model / 2D photograph" combinations were rated differently by both forensic odontologists (Fig. 3) and MSc. students (Fig. 4). It was observed that the MSc. students "excluded the correct 2D case" and were not in agreement with one another in that 3D case as well as in other cases. There was a lower agreement between both groups regarding the opinions reached.

3.4.2 Phase II: 2D-3D Superimposition:

A total of 720 2D-3D superimpositions were conducted by six raters (120 by each rater) during this phase. An increased level of certainty and agreement was observed among the forensic odontologists and the MSc. students when using 3D method. The number of "established" cases increased in both groups as seen in Fig. 5 and 6.

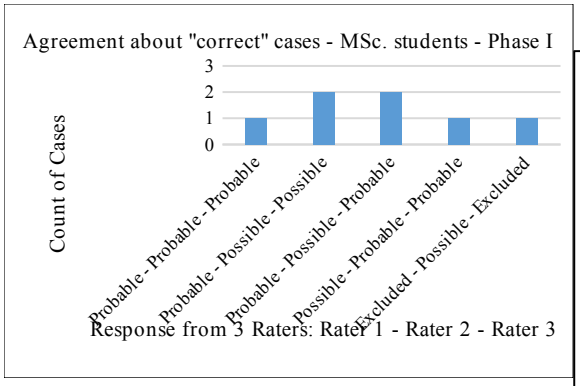


Fig. 3. Opinions of Forensic Odontologists from Visual comparison method.

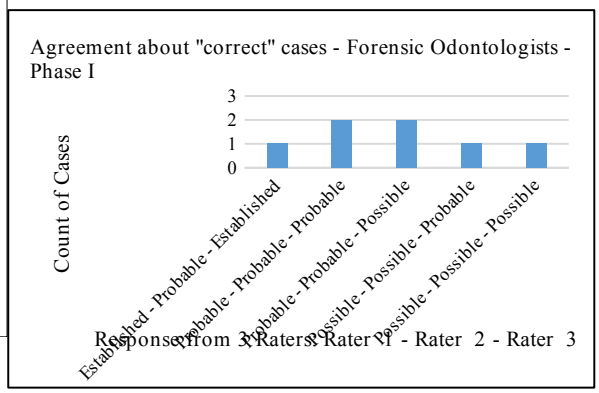


Fig. 4. Opinions of MSc. students from Visual comparison method.

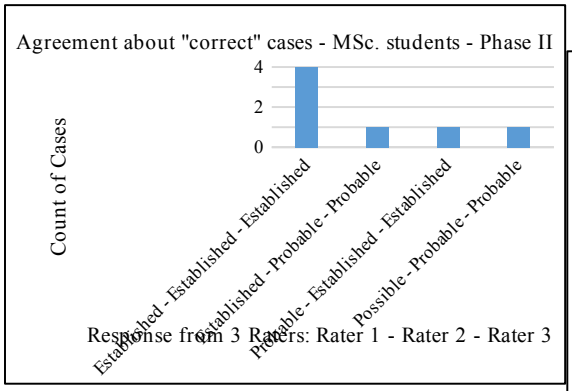


Fig. 5. Opinions of Forensic Odontologists from 2D-3D superimposition.

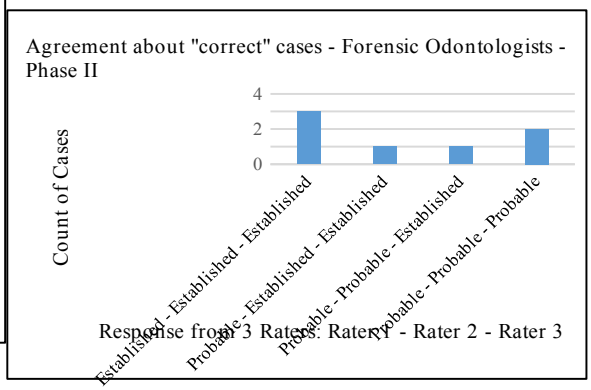


Fig. 6. Opinions of MSc. students from 2D-3D superimposition.

3.5 Statistical comparison of Inter-rater Agreement - Phase I - Visual Comparison:

The intra-class correlation (ICC 2, 1, absolute) was calculated separately for all the 2D cases (photographs) that were compared with a specific 3D case (dental model). The judgements of the raters were treated as an ordinal measure and converted to a numerical code. The reliability of this measure varied depending on the 2D photograph that was being compared. Of the seven "correct" cases with corresponding matches, low ICC (less than 0.75) was observed in five cases among the forensic odontologists in Phase I (Table 4). Cases 3, 6 and 10 did not have matching 2D photographs (true negative cases). In case 3, it was observed that the agreement among the raters was low. While in cases 6 &10, there was high agreement in terms of "excluding" the 2D photographs, which resulted in reduced variability, hence, again a very low ICC score. The MSc. students (Phase I) have high agreement on a non-match (true negative) in case 3, hence, high ICC. While in case 7, the "correct match was excluded" producing negative results. Overall, low agreement was observed among both the groups, and for most of the cases during Phase I.

3D Cases	ICC - Forensic Odontologists		ICC - MSc. students	
	Phase I	Phase II	Phase I	Phase II
1	.688	1.0	.597	1.0
2	.741	.955	.333	.955
3	**.358**	**.00***	**.713**	**.00***
4	.835	1.0	.725	1.0
5	.836	1.0	.471	.941
6	**.011**	**.00***	**.175**	**.00***
7	.506	1.0	**-.061**	.889
8	.732	.941	.697	1.0
9	.673	1.0	.513	1.0
10	**.011**	**.00***	**.048**	**.00***

Table 4 ICC scores of Forensic Odontologists and MSc. students.

*The SPSS software produced a result as .00 because of zero variance (all the scores were 1-exclusion) in that square of data. A low ICC score could be due to low agreement or insufficient variability or a combination [22].

3.6 Statistical comparison of Inter-rater Agreement - Phase II- 2D-3D Superimposition:

Scores were calculated as before for both groups. There were a lot of exclusion scores in relation to cases 3, 6 and 10, (Phase II-Table 4) which leads to a reduced or zero variability. ICC score $\approx$ 1.0 indicates that there is variability in the results and there is total correspondence with the correct answer. Both groups demonstrated the effectiveness of this 3D method during Phase II.

3.7 Intra-rater Agreement:

It is evident that the forensic odontologists (Fig. 7) changed their opinions in 16 cases (76%) whereas, the MSc. students in 20 (95%) (Fig. 8) of the total 21 cases provided. No change of opinion is seen as 0, any change from lower to higher certainty – 1, 2. With regards to the forensic odontologists, raters 2 & 3 were able to conclude

four cases (57%) as “established”, and rater 1 concluded “established” for two cases (28%) during Phase II. In five (72%) out of seven cases, all the MSc. students were able to reach an opinion as “established”. Rater 1 and 3 had “excluded” one correct case (14%) using the visual comparison method, and changed to “possible” when using the 2D-3D superimposition method.

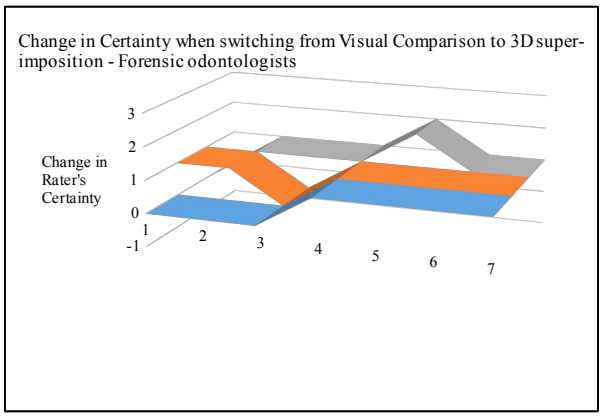


Fig. 7. Change in certainty by the Forensic Odontologists - Phase II.

Fig. 8. Change in certainty by the MSc. students - Phase II.

4. Discussion:

This study demonstrates the feasibility of using a 2D-3D superimposition method in an identification scenario. Photographs of a smile document valuable information of a person’s dentition which could be used as AM dental evidence when dental records are unavailable [23]. Photographic images are 2D projections of 3D objects; thus, objects are difficult to compare if the orientation is not practically identical [10]. This is a major

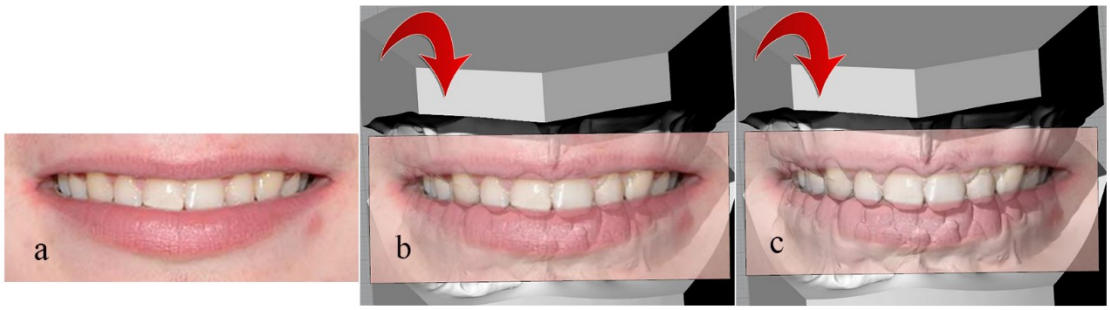
limitation of the 2D–2D comparison methods. It is crucial to reorient the 3D model in the same anatomical position observed in the 2D photograph. A good orientation of the 3D model and a well aligned 2D photograph allows effective comparison during the superimposition process. This method allows users to visually analyse the front teeth, with emphasis on teeth alignment (any malocclusions) and morphological traits. The extent of useful visible dental evidence in an AM photograph when combined with a 3D model as an alternate to multiple PM photographs in a dental identification was explored in this study.

The present study is different to the previous 2D superimposition studies [10,11] with the introduction of 3D visualisation of the dental casts as a novel viewing method in photographic dental identification. For instance, the dental superimposition study by De Angelis et al. [10] requires multiple superimpositions of photographs and this step can be eliminated when using 3D imaging. Bollinger et al. [11] introduced the GrinLine Identification which is a software-assisted manual technique. The limitation in the study was that the PM photographs were in 2D and should reproduce the perspective variations that could be found in an AM photograph. It also requires a series of PM photographs to be made using step-wise increments in horizontal and vertical angulation. Viewing PM images in 3D negates this process.

This study assessed the quality of the conclusion reached in a case; comparison of a 3D case with a correct 2D case, and also how the raters judged the non-matches (Table 3 & 4). The results of this study suggest that the inter-rater and intra-rater reliability using 3D superimposition was highest (ICC $\approx$ 1.0). ICC can be treated as a measure of agreement and how much the score of different raters correlate with one another. When applied to subjective assessments like this, it can also be treated as a measure of objectivity. More non-matches were also introduced into the study design for increased complexity and thorough examination by the raters. ICC scores were consistently higher indicating a greater correspondence between rater's judgements with Phase II - 2D-3D superimposition method. It is noteworthy that the both groups demonstrated strong agreement in cases (3,6,&10) where there was no corresponding 2D match (Table 4).

While there is no single agreed upon value for what constitutes a good or bad ICC [24], a study by Zhu et al. [25] conducted an ICC in a similar context but used a different technique, reported values between 0.48 and 0.76 representing moderate to good levels of reliability. The present study compares very favourably with that because the ICC was between 0.89 and 1.0 when using the 3D superimposition method (Table 4, Phase II). An ICC of 0.89 can be described as good, and 1.0 excellent [22]. The result shows that this method has achieved better reliability.

The photographs of the subjects obtained for this study were found to be of varying quality. The quality of the 2D photograph, number of teeth visible, therapeutic / morphological alterations of the teeth and any variance or inconsistency with the underlying 3D dentition observed may affect the conclusion reached. All raters reported that 3D approach provided more information for reaching a conclusion than 2D approach. A possible explanation for this is the fact that the raters were able to reorient the digital dental model using the 3D software. A 2D-3D superimposition was achieved by this method and a judgment/opinion was expressed by the



investigator based on the orientation and the degree of correspondence of the distinctive morphological traits of the two dentitions. Cases with reduced visibility of the anterior dentition in a smile (Fig. 9) were also analysed using the 3D method.

Fig. 9. A case with reduced visibility of the anterior dentition. 3D model reorientation and superimposition (b and c) enabled the investigator to correctly identify with higher certainty.

The resolution and distortion of the image may be another important limitation when attempting a photographic superimposition. A certain amount of photographic distortion is present when capturing a 3D structure in 2D. Any photograph taken without due consideration could lead to angular distortion. This could be limited when the operator follows a strict protocol by using the right lens and ensure that the camera is always perpendicular (at 90 degrees) [26], which is difficult to achieve from a forensic perspective. Correction of distorted photographs should be handled with caution. According to the National Policing Improvement Agency guidance [27] any digital 'correction' of an image with angular distortion may result in the interpolation of the pixels and is considered as 'reconstruction', which can be applied only as a graphical interpretation and should not be presented as a true image. Most of the AM images analysed in forensic practice are of medium to poor quality due to a combination of poor recording systems and optical distortion. Hence, poor quality and severely distorted images (angular distortion) may not permit a 2D-3D superimposition procedure.

Metric dimensional parameters have been used to assess variation in human dentition [28, 29], however, this method may not be appropriate to describe dental uniqueness with a quantitative approach. It may be more appropriate to consider the arrangement of teeth in the arch and their relative alignment achieved with this 2D-3D superimposition method. The conclusions provided by INTERPOL [3] are well accepted in the field of forensic identification and have not been quantified into probability or percentages. Also, the sensitivity and specificity of the rater groups cannot be calculated as it requires a yes/no judgement. But that is not the judgement this procedure provides, which would be only possible when the sample is a dichotomous data.

Post-orthodontically treated dental samples were used in determining the uniqueness of anterior dentition [14] and exploring the probability of finding matching dentitions in a given population [15]. It is also pertinent to consider that the present study analysed a very small sample of the population who were all orthodontically treated. The rationale for selecting post-orthodontically treated sample (3D dental models and corresponding photographs) was that the orthodontic treatment aims to correct the position of teeth which improves the anterior teeth alignment and appearance of an individual. A latest study by Dyke et al. have investigated the effect of orthodontic treatment on the uniqueness of the human anterior dentition and reported that orthodontic treatment reduced the uniqueness and increased the similarity between dentitions, with a high number of false positive

matches [30]. These well aligned smiles in a photograph could also make the AM and PM 2D photographic comparison procedure difficult. Therefore, a superimposition method was developed to test the applicability of 3D models in identifying the correct 2D-3D matching pairs. The dentitions examined in this study sample were more similar and less unique, but the raters were able to correctly identify all the matching pairs with improved certainty when using the 2D-3D method.

The difference between visual comparison and 2D-3D superimposition match rates and opinions observed through this study were considerable, highlighting the importance of 3D imaging in photographic dental identification. 3D imaging was also used in a recent craniofacial superimposition (CSF) study by Wilkinson and Lofthouse [31] where 2D AM images were aligned and matched to the 3D skull model. The study aimed to compare the reliability of manual and computerised craniofacial superimposition techniques and its applicability for disaster victim identification. The methodology was based upon the morphology of the skull and the closeness of the match between the skull and the AM images (uncalibrated). The study concluded that CSF method could be a useful tool in narrowing down the possible identifications in closed disasters (known list of victims) and recommended high quality AM images without visible distortions.

The present study was conducted by superimposing 2D digital photographs (uncalibrated) and 3D scanned dental casts of living individuals. The central incisor in the 3D model was considered as a reference in guiding with the enhancement of the 2D image (size approximation) due to their position in the arch and increased chance of visibility in the smile. It is permissible to enhance the whole of a cropped image [27]. The transformation of the dental casts into a conventional 3D format assisted in achieving results with improved accuracy and match rates. This method enabled the raters to "exclude all the non-matches" and have increased the certainty of dental identification using photographs of smile. This is the first study combining 3D imaging with the traditional 2D photographs of the person smiling as an aid to accurate forensic dental identification. Conclusions should be made only after considering the quality of the image, number of teeth visible for analysis, dental characteristics, well aligned teeth/arch and superimposition of the image and 3D scan. This technique might not be indicated in cases involving traumatic injuries to the face that may damage the anterior dentition or disrupt the alignment and also in incinerated dental remains that are not suitable for analysis.

It is evident in some case reports [6-9] that the identification of the deceased individuals with no dental records were performed by comparing 2D AM photographs of the person smiling and PM photographs of the deceased. Although the method of identification is decided by the investigating odontologist, with the advancements in 3D imaging, this method may be implemented to eliminate the necessity of series of 2D photographs and precise spatial orientation of the PM image in accordance to the AM images, which is an advantage. In a forensic environment, the 2D photographs can be considered as an analogue to AM images while the 3D models of the scanned dental casts as PM models. This may be applied in forensic cases with no dental records by obtaining PM impressions whenever possible and digitising the dental cast.

The evidence presented in this paper suggests that, were this method to be used in a forensic context, it would improve the performance of the forensic expert over the available 2D comparison methods. Therefore, this

method can be regarded as a forensic tool for improving the certainty of photographic dental identification in future. However, further research should be aimed at the performance of this method in a larger sample of different forensic cases and scenarios.

5. Conclusion:

This study relates to the challenges faced by a forensic odontologist in the area of forensic dental identification requiring photographs. The present study demonstrated that dental comparison was better using 3D PM technology compared to 2D PM comparison. The procedure attempted to reduce the limitations of previous 2D methods such as the spatial orientation of 2D images and is intended to assist forensic experts with a reliable method in dental identification when expressing conclusions on a case. This method is possible, practical and reliable.

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